

Galaxy Counterparts of High-Redshift DLA Systems

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Abstract. Our understanding of the nature of DLA systems at large redshifts, ostensibly progenitors of normal disk galaxies, depends critically on their direct identifications with galaxies, and the resulting measurements of their properties. A few such objects have now been found, reaching out to $z \approx 4.1$. Their observed luminosities are $L \sim L_*$, star formation rates $SFR \sim$ a few M_\odot/yr , physical sizes ~ 20 kpc, and velocity fields of a few hundred km/s, implying masses $> 10^{11} M_\odot$. While their morphology remains uncertain, the observed properties are consistent with those expected of young disk galaxies in the early stages of formation. We also find a statistically significant excess of foreground galaxies near lines of sight to luminous quasars at $z > 4$. This suggests a systematic gravitational lensing magnification of such quasar samples, possibly with important consequences for the estimates of the quasar luminosity function at high redshifts, and the deduced Ω_b in DLA systems found in their spectra.

1 Introduction

Galaxies believed to be responsible for damped Ly α absorption (DLA) systems in the spectra of high-redshift quasars represent a viable population of progenitors of normal disk galaxies [13]. It is also possible that they represent still merging, gas-rich protogalactic clumps, rather than already formed disks. They appear to contain a substantial fraction of the baryons known to exist in normal galaxies today [11]. DLA systems represent an already well-established, *large population* of high- z objects for which the confusion with AGN does not arise.

The crucial question is whether DLA systems represent a population of already assembled massive proto-disks, as advocated, e.g., by Wolfe and collaborators, or whether they are still subgalactic fragments in the process of hierarchical assembly, as favored by many n-body simulators [5]. In order to answer this question, it is essential to obtain firm optical identifications of objects responsible for the DLA absorption, and to determine their physical properties.

Direct imaging of DLA galaxies can provide measurements of their luminosities. From their separation from the QSO line of sight, one can infer their physical sizes. Coupled with the spectroscopic measurements of velocity fields in these systems, one can deduce their dynamical masses. Sizes and H I column densities give the gas masses. Star formation rates can be obtained from the UV continuum luminosity, and from the Ly α line emission, if present.

Clustered companions of DLA systems, all containing AGN, or quasar companions which may be responsible for some associated absorption have been seen in several cases [7, 8, 9], but until recently no normal, isolated DLA sys-

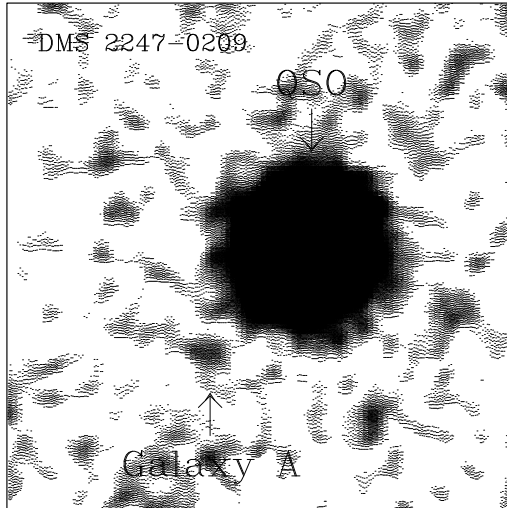


Figure 1: Deep R band Keck image of the field of DMS 2247–0209, a quasar at $z = 4.36$. Galaxy A is an $R \approx 26^m$ object at the redshift of a DLA system at $z = 4.10$ seen in the quasar spectrum. Image shown is 11 arcsec square.

tems themselves. Warren & Moller [12] found emission-line regions associated with a radio-loud quasar PKS 0528–250 at $z = 2.81$, which also has an associated DLA system. The relation of these emission-line objects with the absorber is not clear; yet $\text{Ly}\alpha$ companions of radio-loud quasars have been seen in many cases. The whole point of studying DLA galaxies is to get away from systems dominated by AGN, by selecting isolated, field objects. Even if there are DLA systems associated with quasars, their utility for the purpose of understanding of formation of normal disk galaxies is rather uncertain.

2 Detections of DLA Galaxies at High Redshifts

We discovered for the first time a galaxy responsible for a known, isolated DLA system at $z_{abs} = 3.150$ in the spectrum of a quasar 2233+131 [1]. Its observed physical properties and the derived SFR correspond closely to what may be expected of a young disk galaxy still in the process of formation: no spectroscopic evidence for an AGN, luminosity $\sim L_*$, inferred star formation rate (both from the $\text{Ly}\alpha$ line and the UV continuum) $\text{SFR} \approx 7M_\odot/\text{yr}$, a physical size (from the separation of the absorber portion in the front of the QSO and the counterpart galaxy emission) of ~ 15 kpc in the restframe, and a velocity field with an amplitude of ~ 200 km/s. These properties are exactly what may be expected from a young, massive disk galaxy.

Since then, we have started a systematic search for more such high- z DLA

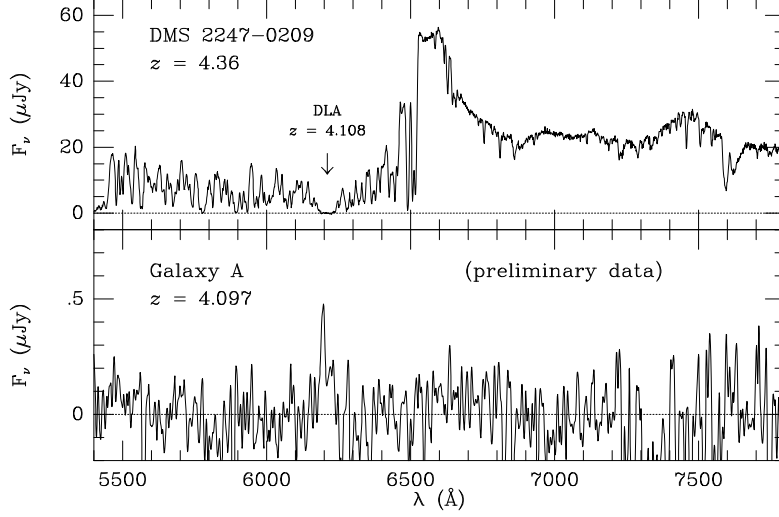


Figure 2: Preliminary Keck spectra of the quasar DMS 2247-0209, and the galaxy A, associated with the DLA system at $z = 4.10$. The glitch to the immediate right of the $\text{Ly}\alpha$ line is an artifact of the sky subtraction.

counterparts at the W.M. Keck telescope. So far, we have found a several candidates, most of which still require more spectroscopy. Typically, these galaxies have $R > 24^m$ and no strong line emission, in agreement with the results found for the field Lyman-break galaxies [10].

The most interesting case so far (Figure 1) is a possible counterpart of a DLA system at $z = 4.1$, seen in the spectrum of the quasar DMS 2247-0209 ($z_{\text{QSO}} = 4.36$) [4]. The object is an $R \approx 26^m$ galaxy seen 3.3 arcsec in projection from the QSO l.o.s. (corresponding to ~ 110 comoving kpc, or ~ 22 proper kpc at the absorber redshift, for $h \sim 0.7$ and $\Omega_0 \sim 0.2$). Weak $\text{Ly}\alpha$ emission line (Figure 2) is detected at $z_{\text{gal}} = 4.097$. Its inferred continuum luminosity is $\sim 0.5L_*$, and the $\text{SFR} \approx 0.7M_\odot/\text{yr}$. In other words, we can now study nearly dwarf galaxies at $z > 4$! Of course, its low luminosity and SFR may be indicative of its extreme youth, rather than its mass.

To summarize, direct galaxy counterparts of DLA systems at $z \sim 3 - 4$ have been found. Their typical magnitudes are $R \sim 25^m$, with separations from the QSO l.o.s. $\sim 2 - 3$ arcsec (the inner limit is due to the seeing). For a reasonable range of cosmological parameters, the corresponding luminosities are $L \sim L_*$, star formation rates (determined from both the UV continuum luminosity and from the $\text{Ly}\alpha$ emission line) are $\text{SFR} \sim \text{a few } M_\odot/\text{yr}$, and the projected physical sizes are ~ 20 kpc. Along with the typical observed velocity fields of $\sim 200 - 300$ km/s, this implies dynamical masses $> 10^{11}M_\odot$.

3 Concluding Comments

These preliminary results support the idea that DLA systems represent likely progenitors of normal disk galaxies today. The populations of DLA systems, of which DLA 2233+131 and DLA 2247-021 may be representative, and of Lyman-break objects studied by Steidel and others [10] may overlap considerably, and they may be tentatively identified as progenitors of typical normal (disk?) galaxies today.

Intriguingly, we have found a significant excess (a $7\text{-}\sigma$ effect) of apparently foreground galaxies near the lines of sight to luminous quasars at $z > 4$, which may be also correlated with the apparent luminosity of the QSO [2]. Our spectroscopy of these galaxies so far shows that nearly all are foreground objects, typically at $z \sim 1$, although at least a few are quasar companions at $z > 4$ [2]. This suggests that gravitational (micro)lensing may be systematically affecting our inferred luminosities of these objects.

This result may have significant implications for our understanding of the evolution of the quasar luminosity function [6], as well as the evolution of the high-redshift absorbers seen in their spectra [11]: both the abundance of high-luminosity quasars and the comoving density of H I in DLA's at high redshifts would be overestimated. However, if a population of optically thick lenses/absorbers exists, that would have the opposite effect [3].

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References

- [1] Djorgovski, S.G., Pahre, M.A., Bechtold, J., & Elston, R. 1996, *Nature*, 382, 234
- [2] Djorgovski, S.G., *et al.* 1997, in preparation
- [3] Fall, S.M., & Pei, Y.C. 1993, *ApJ*, 402, 479
- [4] Hall, P., Osmer, P., Green, R., Porter, A., & Warren, S. 1996, *ApJ*, 462, 614
- [5] Katz, J., Weinberg, D., Hernquist, L., & Miralda-Escude, J. 1996, *ApJ*, 457, L57
- [6] Kennefick, J.D., Djorgovski, S.G., & de Carvalho, R.R. 1995, *AJ*, 110, 2553
- [7] Lowenthal, J., Hogan, C., Green, R., Caulet, A., Woodgate, B., Brown, L., & Foltz C. 1991, *ApJ*, 377, L73
- [8] Macchetto, F., Lipari, S., Giavalisco, M., Turnshek, D., & Sparks, W. 1993, *ApJ*, 404, 511
- [9] Malkan, M., Teplitz, H., & McLean, I. 1995, *ApJ*, 448, L5
- [10] Steidel, C., Giavalisco, M., Pettini, M., Dickinson, M., & Adelberger, K. 1996, *ApJ*, 462, L17
- [11] Storrie-Lombardi, L., McMahon, R., & Irwin, M. 1996, *MNRAS*, 283, L79
- [12] Warren, S., & Moller, P. 1996, *A&A*, 311, 25
- [13] Wolfe, A. 1993, *Ann. NY Acad. Sci.*, 688, 281